Comparative Analysis of Radiance Data from AVIRIS, ASAS, and a Helicopter-borne Spectroradiometer

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Abstract. Multispectral radiance data were acquired by several airborne sensor systems on September 8^{th}, 1990 over the Northern Experimental Forest near Bangor, Maine as part of the Forest Ecosystem Dynamics (FED) Multi-sensor Aircraft Campaign (MAC). High resolution spectral data (5nm to 15nm bandwidths) were acquired nearly simultaneously by the AVIRIS and ASAS imaging spectrometers, and with a non-imaging, helicopter-borne spectroradiometer under extremely clear atmospheric aerosol conditions. Intercomparisons of radiance data acquired with these sensors in the nadir view-angle position are presented for several important ecosystem classes.

I. Introduction

A. Forest Ecosystems Dynamics Project

1. Rationale - The Forest Ecosystems Dynamics (FED) project (Williams et al. 1991) is fundamentally concerned with ecosystem pattern and process within northern forests across a hierarchy of both temporal and spatial scales. The underlying thesis of the FED project is that through careful observation, experiments, and modeling, the interactions of the vegetation, soil, and energy components of the forest ecosystem can be understood. An important aspect of the FED project is to incorporate remote sensing into these modeling efforts in a significant way. The repetitive, multi-scale, multi-spectral observation capabilities afforded by remote sensing platforms make this type of data one of the premier tools for ecosystem modeling, environmental assessment and the detection/monitoring of global change phenomenon.

In this paper we will compare initial results from observations made with three remote sensing sensors flown as part of the FED Multi-sensor Aircraft Campaign (MAC) in September 1990. These instruments are the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS, Green, 1990), the Advanced Solid-State Array Spectroradiometer (ASAS, Irons et al., 1990), and a helicopter-borne Spectron Engineering SE-590 spectrometer. The AVIRIS, ASAS and SE-590 cover a range of both spatial and spectral resolution and coverage at operational altitudes of 20 km, 5 km, and 250 m respectively. A wide range of information may eventually be derived from these data sets with inversion techniques (Boardman, 1990), including information on atmospheric conditions (Gao and Goetz, 1990), vegetation stress (Rock et al., 1990), canopy biochemistry (Martin and Aber, 1990), and a suite of data useful in ecological modeling (Wessman and Curtiss, 1990; Williams et al., 1991).

2. Research Area - The primary research site for this project is a 10 X 10 km area of mixed deciduous and coniferous forests located approximately 40 km north of Bangor, Maine. The research site lies primarily within International Papers' Northern Experimental Forest, just west of the Howland interchange on Interstate 95. Based on an analysis of stand maps, approximately 60% of the site is covered by softwood dominated stands (spruce, hemlock, fir, and white pine); the remaining areas consist mostly of successional hardwoods (birch, poplar, aspen), with some scrub-type vegetation in the poorly drained bog areas. The elevational gradient across the site is approximately 50 m, so topographic effects are slight. This site is ideal for ecological research with an emphasis on input from remote sensing platforms for several reasons, including: its location near a major airport; the nearby research support of a major university; the mix of vegetation types across short distances; the low topographic relief; and the large body of information that is already available for the forest.

B. Data Collection

FED-related field research has been under way on the site since 1988 and its scope is cataloged in Smith et al. (1990). For the purposes of this paper, we are focusing on remotely-sensed optical data gathered during the late summer field campaign of 1990 (September 3-14). More specifically, we are addressing the near-simultaneous acquisition of data from AVIRIS, ASAS, and helicopter overflights on September 8^{th}, 1991, all within an hour of solar noon with solar zenith angles near 40°. Other data sets collected at the site, but not discussed here, include both winter and summer radar imagery (JPL AIRSAR; see Ranson & Sun, 1991), passive microwave data (PBMR & ESTAR), SPOT and Landsat image data, and extensive ground observations of important soil, vegetation, canopy and physical parameters.

The data acquired with AVIRIS provides complete coverage of the Northern Experimental Forest, while ASAS and the helicopter-mounted SE-590 bidirectional reflectance data sets were acquired for specific target areas and landscape features within the study area. For this paper, we have extracted and analyzed data for three major cover types within this northern forest ecosystem; hardwood forest, a conifer forest dominated by hemlock, and a bog containing annual grasses, scrub-type bushes (mostly blueberry) and scattered, dwarfed spruce. While we have chosen to look at only these three sites and cover types for this paper, it represents only an initial review of the large quantity of high quality data available from the FED database.

II. Methods

A. Common Sample Sites

The data used in this analysis were purposely chosen for sites where we had coverage from all three of the airborne instruments. The sites were selected after viewing the digital imagery of the AVIRIS and ASAS, and the video tape of the helicopter flights, to make sure that the instruments actually shared the same site coverage. For the AVIRIS and ASAS data sets we extracted polygons of many contiguous pixels from each band to build the spectral radiance curves for each site. The polygons varied considerably in size, depending on the area of relatively uniform cover type that could be delimited. The bog radiance sample was drawn from an area of 6.8 ha, 4.4 ha for hardwoods, and 3.0 ha for conifer site dominated by hemlock. While hovering at 250 m, the helicopter-borne spectroradiometer "sees" a ground area approximately 5 to 6 m in diameter, a much smaller areal sample than either of the aircraft instruments. However, 40 to 60 scans of data are usually acquired over a given target area, so irradiance data is sampled over a much larger portion of the target area than that sampled during an individual scan.

B. Data Processing

1. AVIRIS (224 10 nm bands, 400 to 2450 nm, 20 X 20 m pixel) - We chose a single 256 X 256 pixel area from the radiometrically corrected AVIRIS image data acquired during Run 3 of the September 8^{th}, 1990 overflights of the FED site. This subset of the entire AVIRIS data set was created to facilitate data handling. This area, roughly 5 X 5 km, is large enough to contain all of the major sites of field observations. The data had to be extracted from two adjacent image/tape segments and mosaicked. To do so we first extracted a three band subset from tape segments 1 and 2 from Run 3 to create a near-IR, red, green image to use in subset identification. The three bands were exported to the FED GIS, running on ERDAS, for display and line and element selection from each of the segments for subsetting purposes. The extraction and mosaicking of the 256 X 256 by 224 band image was done with IDL, as was later analysis and graphic production.

Once the *ca* 29 Mbyte file was extracted, we used a locally written interactive IDL screen digitizing routine to identify the vertices of each of the polygons containing the cover type of interest. With the vertices known, it was a simple matter to extract, band by band, all the pixels contained in each polygon, calculate their mean and standard deviation, and save the data in a new array. The final step in processing entailed the removal of data points within areas of band overlap.

2. ASAS (29 15 nm bands, 465 to 871 nm, 4.25 by 2 m pixel) - ASAS is a unique instrument (Irons et al., 1990) that acquires seven view angles (+45°,+30°,+15°, nadir, -15°,-30°,-45°) over a single target through the use of a tilting optical system. Due to its fine spatial resolution and narrow swath, we had to extract data from each of the flightlines which provided coverage of the three sites of interest. We only used nadir data sets in this analysis in order to match AVIRIS data acquisition conditions (i.e., look angle).

The data sets from ASAS are much smaller than those of AVIRIS, so nadir scenes could be directly imported to IDL without subsetting. The polygon selection and data reduction were carried out exactly as for the AVIRIS data, with means and standard deviations calculated and saved, band by band, for each of the polygons. We used radiometrically calibrated ASAS images provided the Goddard ASAS facility.

3. Helicopter (121 5 nm bands, 400 to 1000 nm, non-imaging) - High resolution spectral data were acquired from a NASA UH-1B helicopter, operating out of the Wallops Flight Facility, using a Spectron Engineering SE-590 spectroradiometer equipped with 1° field-of-view (FOV) optics. Given the 1° FOV and a nominal hover altitude of 250 - 300 m, irradiance from an area 5 to 6 m in diameter is recorded with this non-imaging system. A bore-sighted video camera provides a visual record of the flights, and an audible tone is generated with the acquisition of each scan so that the location of data acquisition can be easily determined. By viewing the video record simultaneously while plotting the 40 to 60 scans of spectral data acquired routinely for a single site, we are able to edit the data set for a given site to eliminate extraneous scans which missed the intended target. All of the remaining spectral scans for a given site are analyzed as a single data set, with the radiometrically calibrated means and standard deviations calculated for comparison to the AVIRIS and ASAS data.

C. Data Analysis

1. Atmospheric Conditions - The atmosphere during the acquisition of these FED data sets was extraordinarily clear. The aerosol optical thickness was measured with an 8-band sun-tracking photometer. Data acquired in 4 of the bands (at 440, 557, 612 and 872 nm) are shown in Figure 1, and compared with similar data acquired during the "best" (i.e., clearest) day encountered during any of the FIFE '87 or '89 intensive field campaigns. This comparison graphically illustrates how exceptional the atmospheric aerosol conditions were during the September 8th, 1991 overflights in Maine. During the AVIRIS overflight window, which extended from approximately 11:30 to 11:45 EDST, aerosol optical thickness was found to be less than 0.04 across all bands, and remained at that level until well into the afternoon when it slightly exceeded 0.04.

2. Conversion to Spectral Reflectance - We have not yet converted either the AVIRIS or ASAS radiance to spectral reflectance, since this will require atmospheric modeling of surface irradiance, path length radiance correction and/or reference to measured ground calibration sites. We simply did not have enough time to carry out this work, but it will be done in the near future in collaboration with FED/NASA researchers. We plan to use the atmospheric models of Tanre (personal communication, 1991) or the approaches of Gao et al. or Boardman (this volume), as well as *in situ* calibration measurements made by Dr. Barry Rock and associates from the University of New Hampshire. The helicopter SE-590 data has been converted to spectral reflectance using measured radiances from field calibration targets at the FED site, so these data can be used to test the atmospheric corrections.

3. Comparisons between Sensors - All three data sets are calibrated radiances in μwatts cm^{-2} sr^{-1} nm^{-1}, and as such can be directly compared across wavelengths in common. The calibrated AVIRIS radiance data, as distributed on tape, only had to be converted from its digital number format by dividing by a scaling factor of 200. The comparative radiances from the three instruments are grouped by vegetation cover type in Figures 2 - 4.

III. Results & Discussion

A. Spectral Radiance Comparisons

We have comparative radiance data from three different vegetated sites (i.e., conifer and hardwood forest and a bog) where radiances measured by all three instruments are available. The radiances from all of these sites are plotted by vegetation type in Figures 2 - 4. In general, the radiance curves from the three sensors are very similar within vegetation type, which is remarkable for such a diversity of instrument types and operational parameters. One very clear aspect of the data sets is the strong difference in additive radiance at shorter wavelengths due to multiple scattering and path length. This is not at all surprising given the altitude range of the sensors, ranging from 250 m to over 20 km. Even though the atmosphere was extremely clear during the overflights (Fig. 1), scattering is significant and the radiance in the visible region cannot be directly compared, as Rayleigh scattering in the blue wavelength region significantly attenuates radiance, particularly in the AVIRIS data set which was acquired through the greatest path length. Some evidence of atmospheric absorption may be present in near- to mid-IR regions of the ASAS and AVIRIS data, but the extent of its effects are not known at this point in time. These observations point out the critical need for atmospheric correction in these multiple sensor data sets even when sky conditions are extremely clear.

The conifer forest site (Fig. 2), dominated by hemlocks and other mixed conifers, has a curve shape in the visible nearly identical to that of the hardwood stand (Figs. 3). However, in the infrared portions of the spectrum radiances are much lower, which is an often described feature of conifer canopies. AVIRIS and ASAS radiance in the near-IR is higher than that of the SE-590, perhaps due to their larger sample/pixel size and the inclusion of varied amounts of hardwood crown elements (mostly beech) in their larger sample areas. The SE-590 samples at the individual crown-level, rather than the canopy-level of the AVIRIS and ASAS, so such differences are expected.

The hardwood stand has very similarly shaped spectral curves (Figs. 3), but it is much brighter in the IR. The superimposition of the data for all 3 sensors is nearly identical except in the visible where scattering has a marked additive path length effect. Sample size differences of the 3 sensors seems to have very little effect on radiance, probably an indicator of uniformity of the canopies within this site.

The bog site (Fig. 4) is a bit unusual in that the IR radiance values recorded by the SE-590 are as bright as those recorded over the hardwood site (Fig. 3), but the bog has the lowest IR radiance values of all the sites from the standpoint of AVIRIS and ASAS. As in the case of the hemlock site (Fig. 2) these differences may be due to the size of the sampling area, as the bog supports a two-storied canopy with sparse black spruce trees over a shrub and sphagnum moss understory. Inspection of the video tape revealed that the SE-590 radiance data were acquired over a more sphagnum moss dominated area within the bog. In the visible wavelength region, detail is masked by Rayleigh scattering in the AVIRIS and ASAS data sets, but the SE-590 shows an unusual plateau in the green to red region. We believe that this increased radiance is due to the moss component with its reduced pigment absorption and strong red coloration.

B. Future Work

Our immediate plans for this AVIRIS radiance data set are to use both measured calibration surface radiances and modeled surface radiance and path length radiance corrections to calculate spectral reflectance for the surface types within the FED research site. Using the FED GIS (geographic information system) we will be able to coregister all of the AVIRIS and other image data sets to a common map projection and use these data sets to sample across the landscape and correlate image-derived data with other corollary data. Rather than hand digitizing of sample polygons, we can use stratified sampling methods to derive the landscape units of interest and extract summary data. Once appropriate algorithms are developed, the radiance or spectral reflectance values can be used alone or with other data from the GIS database to derive ecologically significant data that can be used as input to landscape and global change-related modeling.

IV. Conclusions

The initial comparison of the three high spectral resolution sensors has shown their data to be very similar and remarkably well matched, even prior to atmospheric correction. The spectral matching is excellent, with the red edge of the near-IR plateau very close among all the sensors, and the shape, if not the magnitude of the radiance plots being very close. There is a very pronounced effect of path length radiance in the blue and green portions of the radiance spectra, with the altitude of the platforms playing a clear role. This should be corrected in the near future when the sensor radiances are converted to spectral reflectance.

The results of this initial work with AVIRIS and its comparison with other high resolution spectral data sets from the FED MAC have convinced us of its promise in ecosystem research. Through future work with our collaborators in FED, we will begin to extract critical ecological parameters from the landscape-level AVIRIS data sets. Currently within the FED project, AVIRIS and HIRIS-related research efforts are underway at the leaf, branch and canopy level to elucidate the relationships between spectral reflectance and the water, pigment, nutrient, and biochemical contents of vegetation and litter, and the radiative transfer characteristics of leaves at high spectral resolution. Toward this end, a great deal of field data has already been acquired and is in the process of being analyzed. An additional field campaign with the AVIRIS will take place in early June 1991, at which time many of the questions raised in this initial research will receive further investigation.

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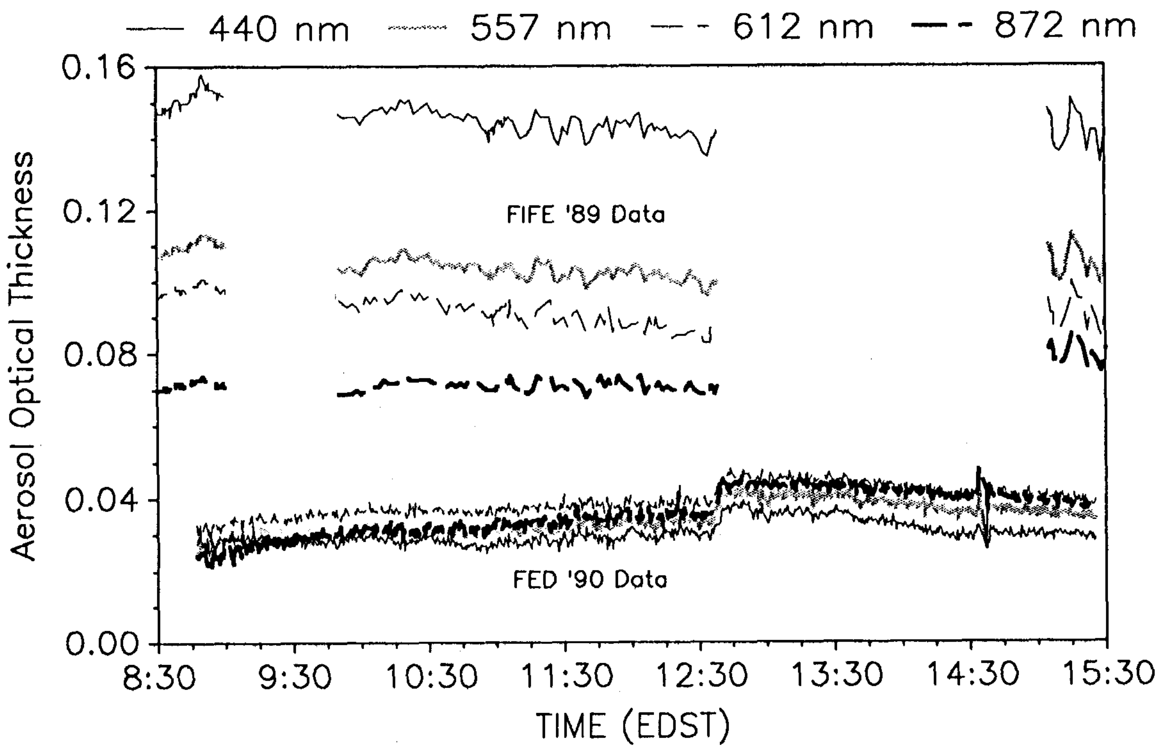

Figure 1. Comparisons of the time course of aerosol optical depth at the FED site near Howland, ME and the FIFE site in Kansas. Separate lines show the optical depth as a function of wavelength.

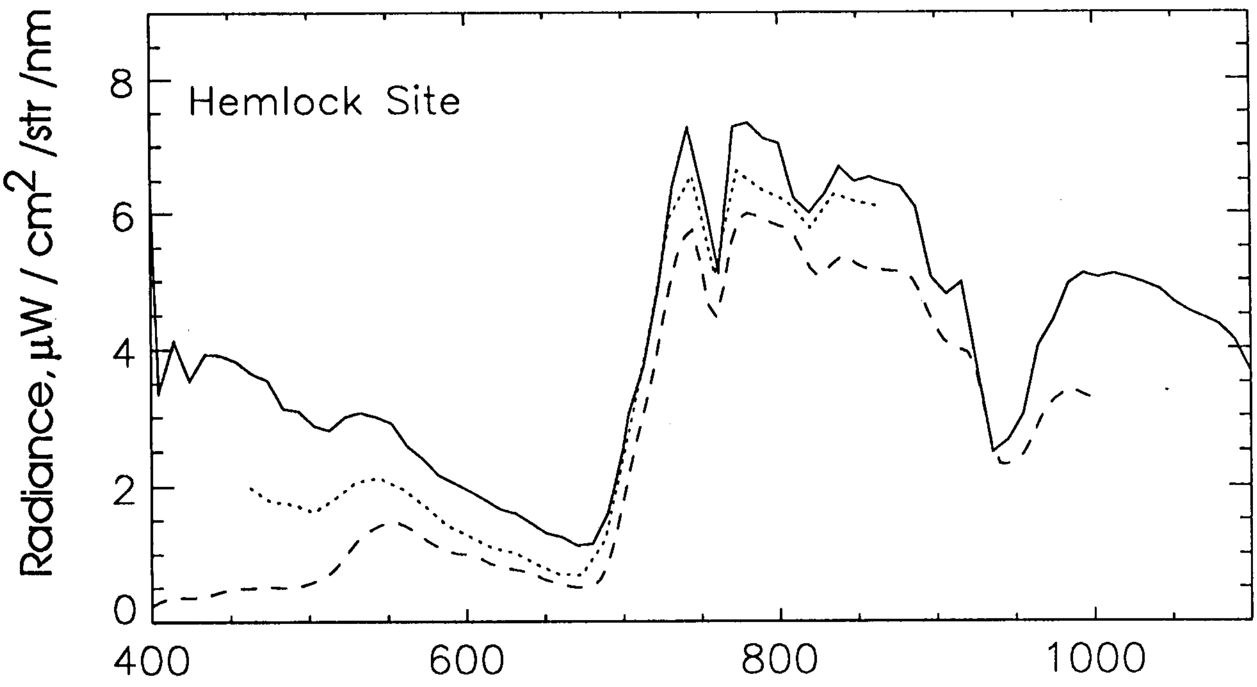

Figure 2. At-sensor radiances for the hemlock site from AVIRIS (solid line), ASAS (dotted line) and SE-590 (dashed line) instruments.

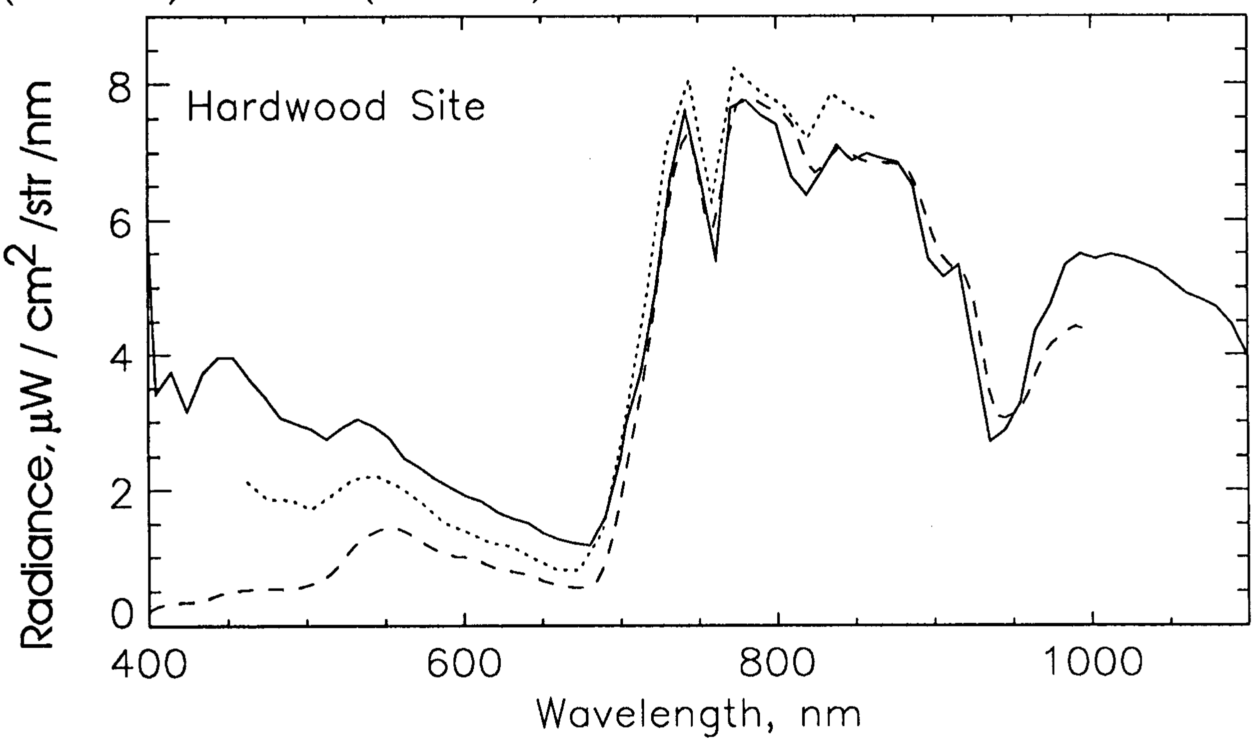

Figure 3. At-sensor radiances for the hardwood site from AVIRIS (solid line), ASAS (dotted line) and SE-590 (dashed line) instruments.

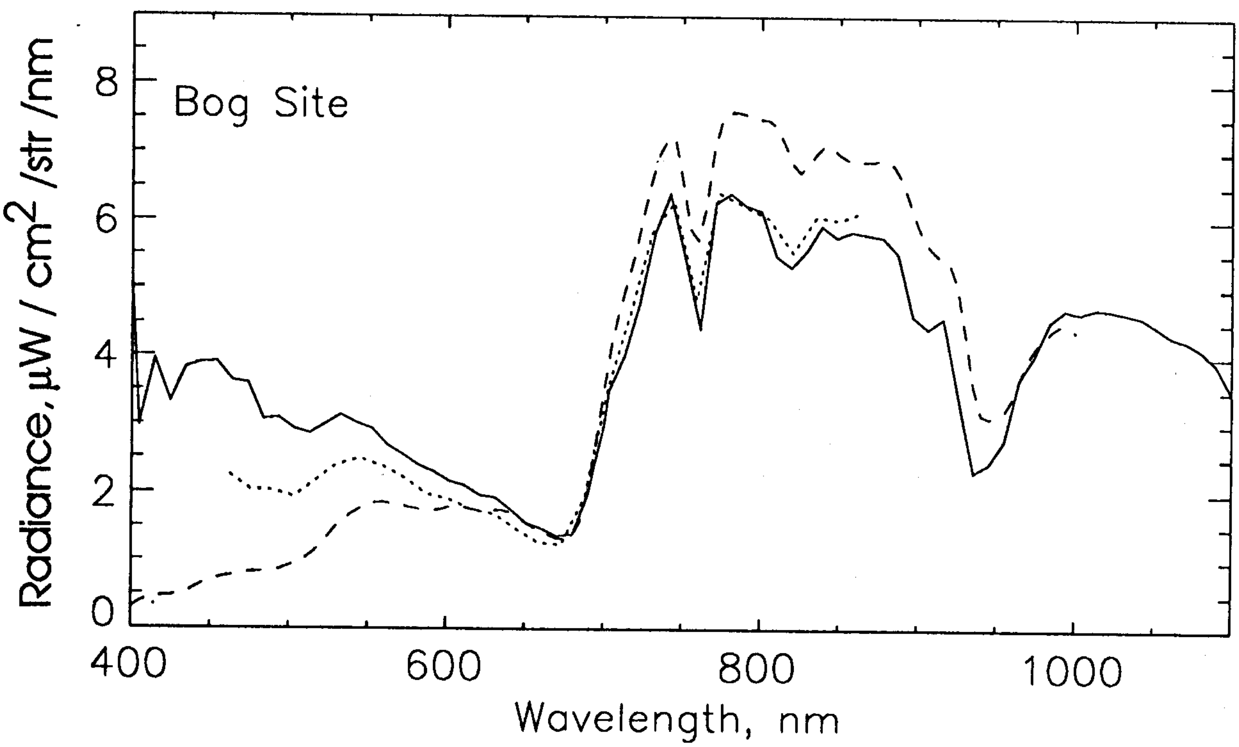

Figure 4. At-sensor radiances for the bog site from AVIRIS (solid line), ASAS (dotted line) and SE-590 (dashed line) instruments.